NATIONAL OPTICAL ASTRONOMY OBSERVATORIES
LONG RANGE PLAN
FY 1986 THROUGH FY 1990

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I. INTRODUCTION

This document sets out a long range plan for the National Optical Astronomy Observatories, an organization made up of the Cerro Tololo Inter-American Observatory (CTIO); the Kitt Peak National Observatory (KPNO); the National Solar Observatory (NSO); and the Advanced Development Program (ADP), together with supporting units and divisions. The NOAO was formed in February, 1984; completion of the appointments of the principal managers in the organization will not be completed until September, 1984--under the circumstances, it has hardly been possible to prepare a long range plan which reflects the input of all the key figures in the new management. The approach adopted has therefore relied heavily on a continuation of past practices in which each observatory prepared a long range plan; and each of these was forwarded to the National Science Foundation after separate review and approval by the AURA Board. The divisional submissions have been combined here. While some attempt has been made to provide coherence in format, and some integration of plans has been made, this cannot be regarded as other than a transitional plan bridging the gap between the previous separate and independent planning exercises and the single integrated long range plan which we intend to prepare in the future.

In the future, we intend that our long range plan will be based on an assessment of the opportunities opening up for U.S. astronomy, and that it will set out an integrated program aimed at realizing them in the most effective way. To be realistic, this must be done in the context of a two-component budget reflecting: (1) the continuation of the existing core program--with allowance for inflation and some growth for 'workload' adjustments; and (2) an add-on component for new initiatives and other program development which cannot be achieved by reprogramming within the basic
budget. The long range plan, therefore, would be formulated in the context of an assessment of what we should be doing at specific times in the future, rather than what we could be doing or would be doing in the absence of new initiatives or explicit actions to change the program's direction.

The planning basis adopted here has been to identify program elements under a series of categories and to cost them out on an annual basis over the next five years. Specifically we identify: (1) the core or level-of-effort program; (2) work-load increases in the core program; (3) well-defined and justified initiatives for major new instrumentation programs and new facilities; (4) computer acquisitions; (5) construction; and (6) major maintenance and facility equipment items. Most instrumentation projects, regular maintenance, and minor construction will be funded from the core budget and these items are included there by implication. The appended budget shows the totals of items (1) and (2) as core; the remaining categories are set out individually.

The program elements (as identified above) are discussed in separate sections of this plan except that the NNTI, being AURA's first priority developmental program, is given a chapter of its own. The high priority given to this project within NOAO and AURA is, of course, fully consistent with the assessment of the Astronomy Survey (Field) Committee which assigned it the top priority for ground-based optical facilities. The other major new initiatives addressed here carry similar broad-based community support. Finally, our plan also attempts to respond to the language of the Field Report (p. 119): "The National Centers face a difficult task in responding to the diverse needs of the heterogeneous user community. They will continue to need the strong
support and encouragement of sponsoring federal agencies in the decade ahead. The centers must be funded at a level that not only provides for the maintenance of existing facilities and staff but also permits the acquisition of appropriate new equipment in addition to the major capital expenditures recommended by the Astronomy Survey Committee."

A separate section is also given over to instrumentation; the items set out there reflect a compilation of the individual divisional submissions with a first attempt at integration. A well integrated instrumentation program within NOAO offers the opportunity of avoiding ineffective duplication of work, and a substantial effort will be made in the coming year to define such a program. A start in that direction has been made by the appointment of an ad hoc committee to advise the NOAO Director on future directions for the infrared program in NOAO.

Before turning to a consideration of the individual program elements comprising this plan, we shall briefly discuss some aspects of the scientific environment within which the program is expected to exist. The nature of this environment, of course, should control to a large extent the details of the long range plan—in some cases (e.g., the NNTT) the program element itself will significantly modify the environment. The discussion is intended to be representative rather than comprehensive.
II. SCIENTIFIC OUTLOOK

To project the scientific environment over the next five years may be perilous but it is necessary for the formulation of a long range plan. This section provides a first attempt; more thoughtful consideration will be given to this matter over the course of the next 12 months to provide a basis for our next long range plan.

For reasons which have been extensively documented, particularly in the Astronomy Survey (Field) Committee report, the construction of a new optical telescope of 15-meter equivalent aperture would open major new areas for research. Such an instrument would provide unprecedented opportunities for high resolution spectroscopy of faint objects in the visible and infrared, for infrared imaging of celestial sources, and of multi-object spectroscopy--to give only three easily-identified areas. The scientific potential of this telescope has placed it at the top priority in the Field Report for ground-based optical instruments and has commended itself to AURA as its first priority project. Whatever the future shape of astronomy, there can be no question but that the NNTT will be responsive to that environment and that it will, in skillful hands, develop much of the future shape of astronomy.

The advent of Space Telescope will, similarly, profoundly influence our program by creating urgent demands for time on ground-based facilities for complementary observations; our long range plan must reflect the associated need for new facilities, and new and more powerful instrumentation. We must anticipate a heavier demand for southern hemisphere observations being driven
by ST (indeed by a whole complex of spacecraft, U.S. and foreign, scheduled for development or flight over the next five to ten years). New approaches to scheduling and use of telescopes to facilitate complementary observations must be formulated and tried. New means of handling and archiving data must also be addressed in the long range plan.

The advent of solid state linear and area detectors has greatly broadened the horizons of the ground-based astronomer. It has led to a renaissance of high resolution spectroscopy; to the ability to detect celestial objects of extremely low brightness; to an ability to gather data rapidly, accurately, and conveniently through a field of individual objects or across the area of an extended source. The opportunities are unprecedented but they place unprecedented demands on our ability to store and to analyze the data. Greater emphasis must be placed on securing the hardware for handling the images and for ensuring convenient access and feasible methods for data-archiving. The prominence given to computer applications in this plan reflects our expectations of the associated demands which will be placed on the NOAO.

While solid-state visible wavelength detectors will certainly be improved (for example, the readout noise can be reduced and the number of pixels on the detector can be increased), more substantial advances can be expected from the developing technology of infrared arrays. Their potential for contributing to astronomy in such areas as planetary physics, star formation, studies of molecular clouds, and galactic nuclei makes it mandatory that NOAO incorporate a significant program in this area in its planning. Infrared instrumentation, too, must be emphasized to take advantage of the spectacular discoveries of
IRAS and to provide the equipment needed to complement other infrared satellites to be flown by U.S. and foreign groups. Here, again, the shortcomings of available southern hemisphere facilities are evident; there is at best a very limited opportunity for U.S. scientists to conduct state-of-the-art infrared observations from the south. Our program proposes to address this through the construction of an infrared-optimized southern hemisphere telescope of 4-meter aperture and a freshly invigorated program of infrared instrumentation.

Renewed attention has recently been given to the need for careful control of the dome interior if we are to obtain optimum seeing. Work at the MMT has clearly shown the benefits which would be obtained in this way and we have initiated action to emulate this example. The removal of inherent atmospheric seeing is a more difficult problem, however. An analysis of this problem indicates that we may be able to provide such correction in the infrared using an adaptive mirror and a program in that area is contained in the long range plan.

Solar astronomy is advancing rapidly and the decade of the 1980s promises exciting developments in which the NOAO should be intimately involved. Investigation of solar global oscillations, for example, has opened the prospect of exploring the interior structure of the sun and stars. The fundamental observational methods and analytical tools exist and NOAO, in collaboration with the user community, has prepared plans to seize this scientific opportunity by building a network of stations for continuous observations of the solar global oscillations. This new initiative is a natural and exciting component of the long range plan.
Finally, advances in detector technology, increases in telescope aperture, improvements in observing conditions (e.g., in seeing), and the ability to acquire and process digital data with low noise and high sensitivity, all open up opportunities to make measurements of much higher precision than in the past; realization of this possibility must surely lead to substantial advances in our understanding of astronomical objects. As a particular example, the ability to measure line-of-sight velocities and acceleration with very high accuracy must pay substantial dividends in studies of stellar pulsations and oscillations; studies of the dynamics of globular clusters and galaxies; and the search for planetary systems around nearby stars. A program for precision measurement of velocities and accelerations is incorporated in this plan since it seems that the technology is appropriate and available at this time for such studies.
III. THE CORE PROGRAM

The core program comprises the activities associated with: (i) maintaining and operating existing facilities and instrumentation; (ii) the research and service activities of the scientific staff; (iii) development of new instrumentation at a fixed level-of-effort; and (iv) administrative and other services required to support this program. The current core program, for example, comprises the existing NOAO program minus the new initiatives (cf Section V). This plan recommends an increase in the scope of the core program, mainly for those staff additions which we believe are needed to discharge the current program satisfactorily. Details are provided in Table 2.

A. Scientific Staff

The scientific staff—which includes tenured, tenure-track, support scientists, and postdoctoral fellows—plays a key role in the management and operation of the observatories' research facilities, in carrying out independent research, and in conception and planning for future needs. The staff activities include assisting visitors in the use of telescopes, instrumentation, and data reduction equipment; in the conception, design, and development of new telescopes and instrumentation, the improvement of existing research facilities, and in devising new methods to increase the efficiency with which telescopic facilities can be used. In the interval covered by this plan the scientific staff at NOAO expects to be increasingly involved with the development of systems and concepts that will ultimately be related to the
NMTT project, the 4-meter infrared optimized telescope, and the Global Oscillation Network. In order to fulfill these added demands and at the same time maintain the Observatories activities at their current level additional staff positions will have to be created during the planning period. The plan provides for this and also includes funding for additions to the Visiting Resident Scientist Program and postdoctoral programs as well as a continuation of the summer student program; these programs are important to maintaining a stimulating scientific atmosphere at all NOAO observatory sites.

B. Operations and Maintenance

NOAO's facilities at Cerro Tololo, Kitt Peak, and Sacramento Peak are among the best in the world for ground-based research. One of the major roles of the national observatories in contemporary astronomy is that of providing state-of-the-art optical and infrared research facilities to all qualified astronomers and support for the efficient and effective use of these facilities. The core program provides for maintenance of the telescopes and instrumentation at the current operational level, allowing for inflation at 5% per year over the next five years. Maintenance of associated administrative and support facilities in Tucson, Sunspot, La Serena, and Santiago is also included in the core budget.

A large portion of the NOAO budget will continue to be spent on operating and maintaining the superb complex of instruments at the three sites, and central computing facilities, for the benefit of U.S. astronomers. The character of this responsibility is gradually changing. Auxiliary instruments and optical array detectors have become exceedingly complex and therefore expensive to
build, operate, and maintain. The task of reducing, displaying, manipulating, and analyzing the expanding stream of data afforded by these advances has become a heavy burden for NOAO. As a consequence, we place substantial emphasis here on the acquisition of new computers and the personnel needed to support the associated programming effort.

A major issue in telescope operations is the increase in the number of visitors who use the telescopes each year. NOAO's existing facilities cannot handle much more than the present load of visitors. At Kitt Peak the growth of the visitor load can be traced to the increase in the number of telescopes on the mountain in the last decade. In addition, the trend toward team research, the growing use of telescopes during the daylight hours, and comparatively short observing runs has accentuated the growth.

C. Instrumentation Projects

New instrumentation is supported mainly under the core program, however, it comprises such a major part of this plan that it is discussed separately in Section VI. For the most part the budget for the proposed instrumentation program is included in the core budget. Some added funds needed for the program set out below are budgetted under the program development category.
IV. NATIONAL NEW TECHNOLOGY TELESCOPE

It has long been clear that progress in critical areas of astronomy will demand the availability of much larger aperture ground-based telescopes than those presently in existence. This demand for larger aperture has arisen as a natural consequence of the increasing demand for data on fainter and fainter objects—it is also increasingly driven by the whole opportunity for optical/infrared astronomy which has followed from the completion or anticipated completion of major complementary facilities in the UV, X-ray, and radio regions of the spectrum. As a consequence, the roles of the national ground-based observatories will change. Implementation of the VLA to its fullest capability, successful launching of the Space Telescope, AXAF and SIRTF, and the data from IRAS will all serve to place unprecedented demands upon ground-based observatories for complementary investigations and observations of newly-discovered phenomena. The case for these investigations and the new, ground-based telescope required to make them has been set forth in several studies—most recently by the NAS Astronomy Survey Committee. These studies have shown the need for a 15-meter class ground-based telescope optimized for optical and infrared observations. Furthermore, there is a stated need for the National Observatory to maintain leadership in the quest for its completion.

For such reasons the NOAO has initiated, as its first priority project, a program for the definition, design, and construction of the 15-meter National New Technology Telescope (NNTT) and its instrumentation. This telescope is the highest priority national infrared/optical facility for the 1980s and will be the largest construction project ever undertaken by NOAO and its
predecessors. We propose to complete a proposal for the NNTT by the end of FY 1986. We expect to be ready for a new start for the NNTT construction in FY 1987, resulting in completion in FY 1991; this plan reflects that schedule.

During FY 1984 the NNTT project passed one of the most important milestones along the path to completion: a selection of the telescope concept. This decision was the product of five years of concept studies, three years of technical feasibility activities, and many contributions from individuals and groups in and out of NOAO concerned with telescope design. A Scientific Advisory Committee (SAC) conducted extensive reviews of two strongly advocated "finalist" concepts. After an 18-month evaluation, the SAC recommended that the NNTT be developed as a "four-barrel" Multiple Mirror Telescope (MMT) with 7.5-meter individual apertures.

This concept selection has initiated a two-year period of engineering and scientific work on the telescope mounting, instrumentation, optics design, and the enclosure. A construction proposal will be completed by the end of FY 1986 to allow construction to commence in FY 1987 if funding is available. Work on the site testing is already in progress at Mauna Kea (Hawaii) and Mt. Graham (Arizona). Evaluation of these sites will be completed by mid-FY 1986 and a selection made soon after that.

Construction of the four-barrel NNTT will require four primary mirrors in the 7-8m diameter range and, possibly, an additional mirror of the same size range to use for testing secondary mirrors (a Hindle sphere), as well as a fifth mirror to allow for optimum efficiency in realuminizing. Our first choice for mirror blanks is the lightweight honeycomb borosilicate glass castings of the
style under development by the University of Arizona and we intend, therefore, to continue support of that development through FY 1986 when the first 7.5m casting is scheduled to be complete.

No mirror polishing facility presently exists anywhere in the world which is capable of figuring 7.5m mirrors. The University of Arizona’s Optical Sciences Center is currently developing a "Large Optical Generator" (LOG) that, when successfully completed, could generate surface figures on 7.5m blanks to, perhaps, 5 μm accuracy. Nonetheless, we must plan for a polishing facility to produce optical surface figures with about 0.1 μm accuracy. The design and development of such a facility is included in this plan. The site for this polishing set-up has not been determined, but could reasonably be in an extension of the existing NOAO optical shop. Another possibility that we will investigate is the optical shop at the University of Arizona Optical Sciences Center. Availability of a polishing capability by early FY 1987 is needed to test feasibility of polishing the 7.5m mirror blank produced in the borosilicate casting project. Although we do not anticipate major problems, the lack of prior experience in polishing such large mirrors mandates a pilot polishing test prior to committing to the final manufacturing method to be used for the NNTT primary optics.

In the first year of construction for the NNTT, we will build any additional polishing machines and facilities that are known to be necessary at that time. We believe, presently, that a maximum of two polishing set-ups will be sufficient for figuring all of the primary mirrors plus the Hindle test sphere.
The NNTT Program is now well launched on a planned schedule that will produce an unprecedented facility that will be available to all U.S. astronomers. With its expertise and experience in the construction and operation of major astronomical facilities, NOAO is in a unique position to lead and participate in the development of telescope technology while at the same time pushing forward in the related areas of detectors and instrumentation that will serve both present day and future astronomers.
V. OTHER NEW INITIATIVES

In addition to the NNTT, which was discussed in the preceding section, NOAO has identified several other initiatives which we wish to pursue. These are discussed briefly below; two of them are subjects of detailed proposals which we hope to place before the National Science Foundation in the near future.

Many other potential initiatives have been identified in discussions with the user community and the staff of NOAO, but their consideration has not progressed to the stage that they can be appropriately addressed here. During the coming 12 months the new NOAO management will have an opportunity to address the desirability of such new initiatives. A few which come to mind are: advanced computer applications, synoptic telescopes, a large aperture solar telescope, and seeing-compensated instruments.

A. Experimental Astrophysics Program

The NOAO Advanced Development Program (ADP) was created "to provide a focal point for the development of innovative instrumentation and experimental techniques for optical and infrared astronomy, and to assume the responsibility for the design, development, and fabrication of new optical and infrared astronomical facilities which are likely to become national facilities (such as the NNTT)."
In addition to its highest priority program, the NNTT, NOAO intends to pursue a number of experimental astrophysics initiatives through the ADP. These initiatives tend to explore techniques in observational astronomy which have the potential of high payoff but which, on the other hand, may be quite risky.

1. **IR Adaptive Optics**

IR Adaptive Optics is the first initiative to be undertaken by the ADP. This program is aimed at correcting atmospheric wavefront distortions in the 2 μm - 20 μm wavelength range by sensing the wavefront disturbances in the light of nearby stars in the visible spectral range. This system will contain 37 adaptive elements which will enable wavefront reconstruction for wavelengths as short as 2 μm on telescopes up to 7.5m in diameter.

With optimum adaptive optics, the 4m aperture telescopes at KPNO and CTIO would have angular resolutions at 2, 4, and 10 μm of 0.1, 0.2, and 0.5 arc seconds respectively. The 15m aperture NNTT would have an angular resolution five times this value or 0.02, 0.05, and 0.1 arc seconds respectively.

An increase in angular resolution allows one to spatially resolve extended objects like galaxies, stellar dust clouds, planets and their satellites, and to study unresolved objects in crowded confused fields as well as giving the astronomer a much improved sensitivity for studying these objects.
2. Stellar Tachometry & Accelerometry

The precise and accurate measurement of line of sight velocities in astronomy and their temporal variations (accelerations) is one of the most basic measurements in astrophysics. Recent identification of low order modes of solar pulsations is leading to a revival of the studies of the solar interior through the addition of a new way of "looking" into the solar interior allowing the study of interior structure and rotation and possibly a solution to the solar neutrino puzzle. It should be possible to study the same type of pulsations in main sequence and other stars. Similarly, the dynamics of clusters of astrophysical objects (globular clusters, open clusters, dwarf galaxies, clusters of galaxies) depend on precise observations of relative doppler shifts for the basic observational input; and precise observations of stellar velocities over long periods of time is one promising method to find planetary systems around other nearby solar type stars. The Gunn-Griffin radial-velocity machine is one way to do this type of observation, however a new principle introduced by Pierre Connes appears to have several substantial advantages and we propose to review these carefully in initiating a program in stellar tachometry and accelerometry.

B. 4-meter Southern Hemisphere Telescope

The 4 meter telescope at Cerro Tololo is the only instrument of its size in the southern hemisphere which is open to all U.S. astronomers. It has been in heavy demand since its inauguration, partly because of its location in an observing site which is amongst the best in the world for both optical and infrared observing, but more so because, from Chile, astronomers have access
to a sky which is remarkably rich in objects of special scientific interest and importance.

Although designed to excel at wide-field imaging and general spectroscopy, the present 4 meter Chile telescope does not match the site potential for high-resolution optical imaging and, most particularly, is deficient for many types of infrared observations. Infrared astronomy was just beginning when the specification for the KPNO and CTIO 4 meter telescopes were drawn up. While the infrared performance can be improved, a new telescope, optimized for the infrared, will be far superior and will double the number of astronomers NOAO can support for work with its largest southern hemisphere telescopes.

With this in mind, NOAO is proposing to build, at low cost, an infrared telescope of 4-meter aperture to be located in Chile on Cerro Tololo or Cerro Morado. This telescope will take advantage of striking advances in telescope and instrument technology over the past decade. We can, thus, confidently expect that the new telescope will significantly exceed the present 4 meter in its pointing, tracking, imaging, and IR performance.

To save on engineering and achieve an infrared telescope that will meet the requirements at the lowest cost, extensive use of the MMT mechanical design (but without the multiple mirrors) will be made. It is anticipated that a 4m blank will be made available by a Canadian source in return for an understanding that Canadian astronomers can have access to the telescope on the same basis as U.S.-sponsored users.
The telescope will provide f/30 and f/7.8 focal ratios via interchangeable top ends. Both foci will be optimized for infrared work; the latter focus will also be available for narrow field (up to 10') optical imaging and spectroscopy to the extent that time is open. Design goals include a very high quality optical system and optimal thermal conditions in the dome to take advantage of Cerro Tololo's good seeing. The telescope will have an rms pointing error of less than 1 arcsec for zenith distances less than 60°. It will offset and track to better than 0.5 arcsec during intervals of 10 minutes of arc (offset) and time (track).

C. Global Oscillation Network

The study of the resonant global oscillations of the sun has developed during the past five years to a vigorous subdiscipline of solar physics. Techniques developed by investigators in this field promise to map the interior of the sun down to its core and to reveal entirely new information on the structure, composition, and differential rotation of the solar interior. The implications for stellar astrophysics of this long-term series of investigations on the sun can hardly be overemphasized. The theory of stellar structure and evolution, the nature of stellar convection, the origins of stellar differential rotation, magnetic field, and stellar activity will all benefit from improved understanding of the solar interior that can be derived from future studies of solar global oscillations.

Progress to date in this field has required the acquisition of very-long-time strings of observations of the radial velocity of the sun, either in zero dimensions (i.e., the whole sun); one dimension, (i.e., a line on the sun);
or, more rarely, in two dimensions over the visible surface. The length of
the time strings determines the frequency resolution in the resulting spectrum
of oscillations and the number of spatial dimensions determines the ease with
which different resonant modes can be isolated. Further progress in the field
requires time strings longer than approximately five continuous days that have
been achieved at the South Pole. A ground-based network of stations,
distributed in longitude seems the most cost-effective route toward attaining
the required set of data on which a large variety of specific investigations
can be based.

While the primary goal of the network is to investigate solar oscillations,
the observations when properly calibrated will also include unique data on the
persistent large scale flows over the solar surface. These, in turn, bear on
the important questions of the origin of solar differential rotation, the
existence of very large scale convective cells, and the operation of the solar
dynamo.

In FY 1984, NOAO/NSO staff in collaboration with a large number of university
scientists established the Global Oscillation Network Group (GONG) to
coordinate efforts towards the construction and utilization of a network. In
FY 1985 the construction of a prototype network station is to begin and
detailed plans will be made for the reduction and analysis of data for a
network.

NOAO will be ready to undertake construction and deployment of the full-scale
network in FY 1985. The network as proposed will consist of six identical
stations; efforts will be made to secure international participation in the
establishment and operation of these stations. Each station will be highly automatic and require the services of a local participant only to exchange data tapes once a day. Observations with the first unit could begin toward the end of FY 1987, and the full network will be observing in mid-1990. Observations with the full network will then proceed for three years; unless specific action is taken to extend the observations, the observing program will cease in FY 1993, followed by one year of data analysis. A data processing facility in Tucson associated with the project will keep pace with the data coming in from the network. The processed data will be placed in an archive that can be accessed by any qualified investigator.
VI. INSTRUMENTATION

Our ultimate intention is to develop and conduct an integrated program of instrumentation within NOAO which will make the best use of the talents and specialized abilities of our staff and respond to the overall needs of U.S. astronomy, in our area of responsibility, as we assess these from our discussions within NOAO and with the user community. It will, naturally, take time to develop such an integrated program; this exercise has barely begun but will be a major emphasis of the new NOAO management during the coming year. The discussion which follows is a first attempt to coordinate some identified instrumentation needs; this will certainly develop during the coming 12 months as new opportunities are identified and integrated priorities are established.

The chapter begins with a discussion of detectors. This is followed by a listing of proposed observing equipment; telescope improvement projects are set out in a final section. A major part of the cost of this instrumentation program is included in the core budget as a line item; add-on costs are included in the program development category.

A. Instrumentation Development

1. Detectors

Several different detector efforts are underway in the NOAO; these generally have different objectives, as the following text indicates, however opportunities for greater integration of the efforts are being studied.
The NOAO detector R&D program is responsible for the procurement and evaluation of detectors for use at the NOAO for optical and infrared astronomy. Over the period of this plan most of this effort will be concentrated on the evaluation of solid state detector arrays, particularly those sensitive in the region beyond 1 μm where there are many opportunities for major improvements. The state of the art has become a small format (58x62 pixels) hybrid array with large pixels (70 – 100 μm). This pixel size is particularly well matched to existing large telescopes. These arrays will be available in indium-antimonide (1 – 5 μm) in FY 1985; similar arrays with other detector materials (Si:Bi, HgCdTe, extrinsic silicon) which will extend the wavelength range to 20 μm are expected to be available later in this planning period. Similarly an attempt will be made to obtain larger formats either through larger numbers of pixels or by utilizing mosaicing techniques.

Devices with quantum efficiencies approaching unity in the visible (e.g., CCDs and next-generation photocathode materials) are becoming available. Optical throughput must be commensurably improved; attention to details throughout the system, particularly in spectroscopy, can lead to striking gains (e.g., with coatings, multi-layer reflective surfaces, grating efficiency improvements).

Similarly, significant gains can be expected if we were to obtain CCDs having low readout noise, wide spectral response, good charge transfer characteristics, and large formats. We will seek to identify sources of good CCDs as they become available and will work on improving the performance of their electronic control systems, especially the readout noise.
We propose to develop a helium-3 cooled far infrared detector which can be operated at the Cassegrain focus of the 4m telescopes. Since millimeter observations can be carried out during dry but non-photometric conditions, this can provide a considerable amount of "free" time for such work. Millimeter and sub-millimeter observations, especially in the southern hemisphere, are likely to become of increasing interest as observations from IRAS and from several southern molecular-line surveys become available.

Detector systems of a separate kind are provided by photon event-counting systems. These continue to play an important role in imaging and spectroscopy (e.g., speckle and speckle-spectroscopy) and their development in current and next-generation systems is to continue under this plan.

The application of infrared detectors will be a major focus in our instrumentation plans--these are more particularly described in the following section, which concentrates on the infrared.

2. **Infrared Instrumentation**

Infrared arrays will have a major impact on the science, making possible a fresh attack on some of the most important and exciting problems in astrophysics today, including studies of early stages of star formation, the nature of active galactic nuclei, mass loss around late-type stars, and follow-up of the fascinating discoveries of IRAS. Infrared arrays will have particular value for spectroscopy and for direct imaging and we anticipate extensive applications in each area.
In spectroscopy, we will concentrate particularly in the 1-13 μm region where we find, at once, a much reduced extinction by interstellar dust, strong fine-structure and recombination lines, fundamental vibration and rotation bands of abundant molecules, vibration transitions in solids, and several broad unidentified features.

To capitalize on the opportunities opened here, we propose to apply infrared arrays in spectroscopy in three ways: (a) a low/moderate resolution spectrometer; (b) a cryogenic echelle; and (c) an FTS post-disperser. These are discussed separately below.

(a) **Low/moderate resolution spectrometer.** This instrument, together with a high performance InSb array will be a very powerful tool for studies of a wide range of astronomical sources, including study of faint IRAS sources, looking for spectral signatures, emission lines, redshifts, the composition of obscured objects, emission line studies in H II regions, and active galactic nuclei. Both in Chile and Tucson, we have had substantial experience with the technology of cooled-grating spectrometers and the incorporation of an array detector in these should be relatively straightforward.

(b) **Cryogenic echelle.** For the 1-5 μm region, a cryogenic echelle has been proposed for use at the 4m telescopes. The spectral resolution of this device would be ~ 3 x 10^4, adequate to resolve line widths of > 10 km/sec. This instrument will be extremely valuable for studying the dynamics, compositions and isotopic ratios in a wide variety of environments ranging from nearby main sequence stars, red giants in globular clusters and compact objects in regions of star formation, to sources in the nuclei of our galaxy and others.
(c) **FTS post disperser.** For wavelengths beyond about 3 μm, the sensitivity of the 4m FTS on Kitt Peak can be improved by reducing the spectral bandpass recorded by a single detector. Thus, by adapting a cooled, multichannel, grating spectrometer to the FTS, very high resolution (> 10⁵) observations can be obtained for planets, large numbers of late type stars, and brighter examples of compact sources in star formation regions.

Two applications of IR arrays which we propose to follow in a direct imaging mode are panoramic imaging and "speckle" imaging.

For **panoramic imaging**, arrays of InSb (1-5 μm) or Si:Ga (8-14 μm) are expected to have pixel response comparable to or better than those obtainable with present day single-element detectors. Use of these arrays for direct imaging will give enormous advantages in observing efficiency or sensitivity in contrast to single-detector mapping techniques. In addition, changes in sky transparency will be far less critical in the panoramic mode. In the shorter wavelength regime, we will typically match the pixel size to the seeing disk (about 0.6 arcsec on the 4-meters), diminishing the difference between "direct" and "speckle" imaging. Examples of some observational possibilities opened up in this way are:

- **Imaging of galaxies in the infrared.** Filters for the 2.3 μm CO and 1.8 μm H₂O bands can delineate regions of late-type stars; narrow band filters isolating the Brackett recombination lines will identify H II and star-formation regions.
• **Location and classification of IRAS sources.** Accurate positions are a prerequisite for observations by small beam instruments such as the FTS or VLA radio facility.

• **Efficient "photometry" of stars in globular clusters,** e.g., to determine the location of the giant branch and the IR metallicity scale.

• **Morphology of protostellar objects and bipolar nebulae.** Scattering lobes may be identified by imaging polarimetry. Narrow band filters around the H$_2$ S(1) line (2.122 µm) can be used as a probe of shock fronts associated with high velocity gas flows.

Implementation of two-dimensional infrared arrays for speckle imaging capable of resolution ~ 0.1 arcsec in the 1-3 µm region, will produce a substantial leap forward in performance and efficiency. The individual pixels of these arrays will be at least equal in performance to the present day single detectors; the two-dimensional format will yield substantial gain in duty cycle; and two-dimensional format frames will be amenable to phase-reconstruction algorithms, now being implemented with visible arrays, which allow reconstruction of non-symmetric images. Specific applications would include:

• **The study of our galactic center.** Each increase in spatial resolution has yielded exciting information on this complex region. Most recently, the compact "non-thermal" source IRS 16 very near the dynamical center has been resolved into three components on the order
of 0.5" in size. Higher spatial resolution studies of the stellar distribution in this region will complement the VLA maps of the gas distribution.

- **High resolution studies of active galactic nuclei**, such as M82, galaxies such as NGC 1068 and Markarian 231, and Arp 220, discovered by IRAS to have the highest infrared-to-visible luminosity ratio of any known galaxy.

- **Possible multiplicity in protostellar and young stellar objects** (e.g. T Tau). Several such objects with "composite" spectra have been resolved into multiple objects at ~1 arcsec resolution.

- **Investigation of stars at or below the main-sequence luminosity limit**. Because of their low temperature, these objects are amenable to study only in the infrared, particularly as binary companions. In such cases, speckle can provide orbital information leading to a mass determination for these stars.

A separate area of infrared instrumentation is in magnetometry; our initial approach here will be studies of solar active regions through development of an IR magnetograph. The Zeeman splitting of a spectrum line varies as the square of its wavelength which greatly enhances the value of infrared lines in magnetic field measurements, even when combined with a parallel reduction in sensitivity arising from increased line width. The recently discovered solar emission lines at 12 μm open up a fine opportunity to study solar field with high sensitivity and a program is planned to exploit these new results. The
Fourier Transform Spectrometer (FTS) and the McMath telescope will be used in combination with sensitive infrared detectors. We plan to install one or two infrared array detectors at the FTS for further studies of solar magnetic fields in two dimensions.

3. Instrumentation for the Visible

We describe very briefly the characteristics of a number of instruments whose completion will open significant horizons for astronomers at the National Optical Observatories. Realistically, we cannot expect to build or acquire all these, nor have we yet gone through the exercise of prioritizing them. All are regarded as desirable, many as essential, and all merit inclusion here.

- **NNTT prototype instruments.** The scientific success of the NNTT will be critically dependent upon its instrumentation. Two major instrument systems planned for the NNTT are fiber-fed spectroscopic systems and dense-packed CCD arrays for wide field imaging. Operational prototypes of both systems will be constructed for use on NOAO's 4-meter telescopes, thereby dramatically improving their scientific capabilities while concurrently testing the feasibility of such approaches for future large telescopes. This prototype approach will be adopted for other NNTT instruments as found appropriate.

- A high-resolution, high signal-to-noise optical spectrometer is planned for the CTIO 4m telescope. It is presently possible to obtain a maximum resolution of about 8-10 km/sec with digital detectors and
using a wide enough slit to observe fainter objects. About four times higher resolution will provide a reasonable match to the widths of the absorption lines in the spectra of dwarf stars, and thus permit line profile studies and better detection of weak absorption lines. We are studying a fiber-optics-fed echelle spectrograph mound on the telescope pier for these applications.

- A multi-object, remotely controllable fiber optics feed is planned for use with the 4m and possibly the 1.5m spectrographs. This will offer a great increase in the efficiency of these telescopes for some types of observing.

- A spectropolarimeter device is proposed for addition to the complement of existing spectrographs. This will be designed to work at fairly high resolution for studies of the profiles of emission lines in the spectra of active galaxies.

- The High Resolution Imaging Spectrometer (HRIS), a speckle spectrometer will be developed with the hope of obtaining improved angular resolution for spectroscopy. The instrumental design will allow direct imaging through moderately wide passbands, slit spectroscopy, or monochromatic imaging in multiple passbands. Scientific problems which this technique will open up for study include the fine structure of gas clouds in galactic nuclei, detailed study of compact galactic nebulae, shells and disks around nearby stars, and searches for gravitationally lensed quasars. Use of this technique requires detectors of high efficiency, fast response time, and stable
geometric characteristics such as the current generation of 2-D photon counters. Experience gained in this program may well be useful in exploiting very large ground-based telescopes most effectively.

- A **fast blue-optimized spectrograph camera** for use with the 4m R-C and echelle spectrographs is proposed for early implementation. Later during the period of this plan a double spectrograph will be constructed to utilize that camera, or a version thereof, to feed a two-dimensional photon counting detector for blue sensitivity and a red-optimized camera to feed an integrating CCD detector for red sensitivity. Such a spectrograph could be fed using the currently available aperture plate/slit technique or remotely controllable fiber-optic feeds.

- A **multi-color prime focus camera** to permit simultaneous multi-band CCD photometry. This system will be similar to a 3-channel photometer but will utilize three CCD detector heads.

- **Narrow-band imaging.** A narrow-band imaging system based on a tunable, dual-etaion Fabry-Perot filter is proposed to provide the observer with maximal flexibility in choice of bandwidth and wavelength range. This instrument will be compact enough to be moved easily between the KPNO and CTIO sites. We envision the primary application of the NOVI (NOAO Velocity Interferometer) to be in the area of velocity resolved imaging, e.g., in studying the full two-dimensional velocity fields of emission line gas in galaxies or nebulae.
- **Fiber Optics Application.** The use of fiber optics with telescope instrumentation potentially provides for greater reliability, added convenience, and in some instances (e.g., spectropolarimetry) enhancing the accuracy of the data obtained. We propose to continue a laboratory effort, therefore, which will be aimed at understanding the characteristics of fiber optics for astronomical application and remaining up to date on new developments in this area.

4. **Remote Observing**

This area will receive increasing attention in future years in the NOAO. The distance, travel time, and cost involved in bringing observers to the observing sites implies a clear need for remote observing links between NOAO's facilities (especially in Chile) and its users. One possibility will be a multi-observatory time-shared observing link for use by a large number of users who would receive but not transmit data. Observatories within the United States might then be used by observers working from their home institutions. When affordable satellite links become available, the service can be extended to CTIO and to observers in Canada and Europe. Observers will communicate back to observatories via land line voice and terminal links. The evolution of this facility is being approached conservatively since the hardware and software available for such a system are changing rapidly.

B. **Telescope Improvement Projects**

The following projects are proposed:
• **Thin Vacuum Tower Window.** The Sacramento Peak Tower is presently capable of forming solar images with spatial resolution occasionally approaching 0.2". It is perhaps the best available tool in the world for the study of small-scale magnetic fields. It is handicapped, however, by the depolarization that takes place in its entrance window. Replacement of the present 4-inch thick window with a much thinner fused quartz window (perhaps 1 inch in thickness), opens the prospect of measuring the four Stokes parameters that describe the state of polarization of the solar radiation field as a function of wavelength. These primary data can be interpreted to yield vector magnetic fields within, and near, elementary flux tubes. If successful, this program will lead to the development of a Stokes Polarimeter in the early years of this plan.

• **Upgrading Kitt Peak Vacuum Telescope.** The Kitt Peak Vacuum Telescope is equipped with a 512 channel magnetograph. It provides daily spectroheliograms in the He I λ 10830 (used to track coronal holes) and daily magnetograms to a large number of U.S. and foreign scientists. It is also used occasionally for specific, short-term investigations. NASA contributes resources to operate the telescope. This instrument dates to the Skylab era (1973-1974) and we propose a number of improvements to enhance image quality (focus stabilization, elimination of vibration, and active seeing compensation). A new grating (300 λ/mm, 10"x14") will improve system performance in all areas and will make possible new spectroscopic programs. Installation of 2-D reticons will improve the calibration of longitudinal magnetic
field measurements and allow simultaneous line profile observations. Improvements in operating and data display software are planned.

- Upgrading McMath Nighttime Capabilities. Several additions and improvements to the McMath Stellar Spectroscopy Facility are proposed. An ultra-stable stellar spectrograph is needed to permit observations of non-radial oscillations. A prototype, begun in FY 1983 but shelved for lack of funds will be completed and installed in FY 1986. A second CCD detector at the existing stellar spectrograph will allow moderate s/n observations (s/n < 200) of fainter objects.

- Upgrading FTS. The Fourier Transform Spectrometer (FTS) on Kitt Peak remains one of the most powerful sources of laboratory spectroscopic data of astrophysical interest. Wavelengths and oscillator strengths for a large number of spectral lines of cosmically abundant light elements, particularly in the infrared, have been measured. Much work remains to be done on the transition group metals (vanadium, cobalt, manganese) in which hyperfine splitting complicates the determination of oscillator strengths. The FTS also produces unique data on astrophysically important molecules in support of solar, stellar, and planetary astronomy.

Molecular spectroscopists in the planetary and atmospheric fields have frequently requested a temperature-controlled, multi-pass absorption cell for use with the FTS. Having temperature as an adjustable parameter will greatly improve an investigator's ability to obtain pressure shifts over a broader range of line intensities.
• Upgrading Sacramento Peak Coronal Photometer. The three-channel differential coronal photometer at Sacramento Peak provides unique synoptic observations of coronal ejections, condensations over active regions. We propose to upgrade the system to provide more continuous, higher quality observations. A spare coronagraph (40 cm diameter) on the spar at the Big Dome will be refurbished to mate with the photometer, and so provide an independent instrument for continuous monitoring of coronal activity. A design study for three CCD detectors for the three-channel photometer will be undertaken. If desirable, these detectors will be added to the new coronagraph.

NOAO plans to continue improving the capabilities of the existing nighttime telescopes in order that the telescope facilities continue to be matched to the ever-increasing needs of the instrumentation. Increasing oversubscription rates, improved detector efficiency, and increased complexity of instrumentation require that the efficiency of observing be improved commensurately.

• New automatic guiders will utilize either image-dissector tube sensors or TV guiders. These will improve the quality of the data taken both by better guiding than can be provided by individuals as well as by freeing the astronomer for quick-look review of the data.

• Automatic dome control; this is a simple matter of adding a coarse encoder to the dome track and implementing software developed for the larger telescopes.
• Console room observing has become a necessity with array detectors such as the CCDs. Full computer control of the instrumentation is necessary if console room observing is to be fully implemented. As older instruments are retired, their replacements are being designed and fabricated with this in mind. With the distributed-processing philosophy, most new instruments will have either micro-computers or micro-processors built into them to provide control and sequencing functions. The communication to the facility host computer will be simple and strictly for the purpose of commands and data recording. Existing spectrographs are being upgraded to provide remote control of apertures, calibration sources, etc. Provision for more classical, on-the-platform observing will be maintained at all facilities to permit the testing and development of new equipment as well as the use of non-NOAO equipment.
VII. COMPUTERS

Astronomy of the mid-to-late 1980s will place severe demands on NOAO for development and maintenance of software for data reduction and analysis, and in the provision of facilities for its use, not only on-site but remotely from many institutions around the world. Numerous issues of long-range impact must be considered in our planning. Some, such as data-base facilities and high-bandwidth communications, must be resolved in coming years, and hence their planning must be addressed today.

The Central Computer Services (CCS) unit of NOAO is to come into existence at the beginning of FY 1985 and will have responsibility for coordination and planning of computer hardware and software acquisition and development for all portions of NOAO. In this way we hope that inefficiencies in computer application, which in the past have resulted from lack of a common management structure, will be overcome with consequent benefits both to in-house staff and the scientific community making use of our national facilities. A substantial step in this direction has already been taken with the decision to purchase VAX computers for use in La Serena, thus standardizing with the hardware acquired in Tucson. Similarly, the IRAF imaging-processing software will become a standard for application throughout the NOAO. A further example of coordination will be in the development and use of the so-called supermicro systems which will be planned from the beginning on an NOAO-wide basis.
The material given below addresses the computer implementation plan on a site basis; however, it must be emphasized again that the planning will be coordinated throughout NOAO.

A. NOAO-Tucson

The NOAO-Tucson computer plan has been based on extrapolation of present trends in research, instrumentation, and computer hardware.

We have several goals: to provide sufficient computing power to completely and quickly reduce data taken with NOAO-Tucson telescopes, to develop data reduction and analysis software for use at NOAO and in the astronomical community, and to analyze reduced data taken by NOAO staff members and by other astronomers that lack sufficient resources at their home institutions. In addition, we must provide extensive general purpose computing resources for staff scientific research (including theoretical astrophysics computing) and for support of technical, engineering, and operational programs.

In FY 1985, the existing Cyber is to be replaced with a DEC "SuperVAX". The SuperVAX will serve as a host computer in our network capable of the high-speed, high-bandwidth computing necessary to meet our data reduction needs. Three of the VAX-11/750s (and future supermicro systems) will serve as satellite systems supporting one or two interactive IRAF users.

The SuperVAX will also serve as a large-scale general purpose interactive computer for scientific, engineering, and technical purposes. It will support extensive peripherals including an array processor, high speed, high density
tape drives, and archival storage systems. The initial configuration of the SuperVAX will be powerful but will leave ample room for growth.

By FY 1986 we project that the interactive capacity of our three VAX-11/750 IRAF satellite computers will become saturated as the demand from local and visiting astronomers for interactive data analysis exceeds our capacity. To meet this need, we plan to obtain a small network of supermicro workstations.

In FY 1986 and FY 1987, we shall expand the capabilities of the SuperVAX with increased memory, disk and archival storage, and the addition of array processors.

The amount of data flowing from the telescopes is already swamping our tape storage facilities; to address this problem we will equip the SuperVAX with high density tape drives (6250 bpi); we are also following the development of technologies such as optical disks and vertical magnetic recording.

Computer-to-computer communication via wide ranging networks is also in our long range plan. As high data rate transmission becomes cheaper and more widespread, data links between Tucson, Kitt Peak, Cerro Tololo, Sunspot, and other astronomical centers should become practical facilitating remote observing, scientific collaboration with shared data, and remote access to databases. We certainly envision dramatic advances in this technology in the next five years.
B. NOAO-Kitt Peak

On Kitt Peak we have two goals for computing resources; first to provide a set of modern computer systems for instrument and telescope control, data acquisition and "quick-look" data reduction and second, to provide access to powerful computing facilities for data reduction and analysis.

The obsolete Varian telescope control and data acquisition computers on Kitt Peak are being replaced with a family of compatible PDP-11 and LSI-11 computers manufactured by Digital Equipment Corporation (DEC). Conversion of these computers continues and should be completed in FY 1986. In addition, the "dedicated" DEC LSI-11 instrument control computers used to run the CCD systems are compatible with and run the same software as the telescope/instrument control computers. We will require several more of these dedicated computers over the next few years.

While future needs for data acquisition/instrument control computers on Kitt Peak remain undefined we do not expect to have to replace the DEC dome computers for the foreseeable future; rather we should be able to modernize and enhance the performance of these systems with incremental upgrades without any software upheaval.

Our plans for providing data reduction and analysis facilities on Kitt Peak have fluctuated between several alternatives: locate one or more "VAX class" computers in central locations on the mountain (possibly networked to workstations in the domes), place separate computers in each dome, or provide a high speed link between a Kitt Peak-wide network of computers and the
powerful computers located in Tucson. Resolution of this complex question will be a high priority for the NOAO over the coming year or two.

C. NOAO-La Serena

CTIO's current plan for computers calls for the installation of two VAX-11/750s in La Serena sometime during FY 1985. These computers will be dedicated in large part to image processing by visitors and staff with the IRAF software package. The MV/8000 will also have the IRAF software and will be used for general scientific computing, software and detector development, as well as for administrative needs and word processing. We expect that these three computers will be able to handle much of the demand anticipated at La Serena over the next five years. However, we shall continue to investigate supermicro computer workstations as a cost-effective way of increasing still further the image processing capability.

As the pressures on the central La Serena computer increase, it will become increasingly difficult for administration and secretarial users to gain access to the machine; it is proposed to acquire suitable micro-computers in FY 1986 for this task and that of shipping and receiving.

D. NOAO-Cerro Tololo

On Cerro Tololo, much of the effort over the next five years will be dedicated to bringing the data acquisition computer hardware into much closer compatibility with that of Kitt Peak. This will allow us to take advantage of the much larger software manpower available at NOAO-Tucson and will also
provide similar, if not identical, user interfaces to instrumentation at both KPNO and CTIO. The move to fuller hardware compatibility has already begun with the construction of four LSI-11/73 CCD controller computers in FY 1984 and 1985 which will use the KPNO-developed Forth-11 CCD data acquisition and reduction software. In FY 1985 we plan to convert the two LSI-11/23+ controlled 2D-Frutti detectors to the Forth-11 software.

More powerful facilities for data reduction at the CTIO telescopes are also planned for the next five years. Several options are presently being investigated, including a single VAX-11/750 computer or a number of supermicro computers. The goal will be to provide the observer with access to a powerful computer running the IRAF software for either on-line or next day image reductions and analyses.

E. NOAO-Sacramento Peak

The central computer at Sacramento Peak (Perkin-Elmer 3242) was purchased in 1978. It is used primarily for image processing, spectral line data reduction, and for theoretical calculations. User pressure on the machine has mounted steadily as CCD detectors have come into general use around the observatory. NOAO must plan for a replacement for the computer within two years. A DEC machine, compatible with equipment at the other NOAO facilities, will be purchased. The two other Perkin-Elmer computers at Sacramento Peak (at the Tower and Dome) need additional memory to cope with the larger data arrays acquired in current observations. Software improvements such as Perkin-Elmer UNIX will be implemented rapidly to facilitate program development.
F. IRAF

In addition to computer hardware, data reduction and analysis software is a parallel and inseparable issue in our planning. NOAO's IRAF is a multiyear project which directly addresses the current software "bottleneck." IRAF focuses our reduction and analysis software effort providing the framework for high quality, supportable programs. All new and much of the existing data reduction and analysis software developed at NOAO-Tucson will be incorporated into IRAF.

The successor of KPNO's highly successful Interactive Picture Processing System (IPPS), IRAF has been under development for three years and should be in regular use in FY 1985 at NOAO facilities and the Space Telescope Science Institute. IRAF provides an elegant and powerful programming environment for astronomical image processing, data reduction, and data analysis that will be used both to support standard software packages and to provide a flexible framework for scientists to program their own applications. IRAF is also a highly transportable system, designed to be easily exported to our user institutions and to survive across several future generations of computer architecture.
VIII. CONSTRUCTION

As part of this plan NOAO includes construction projects, several of which continue to be high priority because of their safety aspect, possible impact on members of the astronomical community who rely upon NOAO's facilities to conduct their research, or the public who visit these facilities each year.

A. NOAO-Cerro Tololo

The 23 mile road between Tololo and the public highway needs to be improved. It remains a dangerous road for drivers unfamiliar with its curves and steep dropoffs. Furthermore it has been severely damaged and closed for nearly two weeks by the heavy rain and snowstorms of the past two winters. It is proposed to install guard rails for the most dangerous 10 miles of the road and to pave the road.

Since 1963-65 the generators, warehouse, garage, and several shops on Tololo have been housed in three "temporary" buildings of structural steel covered only with corrugated zinc sheeting. The buildings are unsuitable for the mountain weather conditions and are becoming less safe with age. It is proposed to replace them with prefabricated service buildings.

The increase in the number of visiting astronomers and the number of teams coming to observe on Tololo, combined with the construction of the new infrared telescope, will exceed the capacity of the astronomers' dormitory. We propose to build a ten-room annex to the existing dormitory.
The present CTIO visitors' center is a converted shop building that is poorly equipped to receive the nearly 5000 people who visit Cerro Tololo each year. It should be refurbished and fitted with exhibits suitable for the best known observatory in Chile.

B. NOAO-Kitt Peak

The water system at Kitt Peak is often pushed to its maximum capacity because it depends upon collecting runoff from rainfall and melting snow. A water well and pumping stations are required to provide a dependable source of potable water.

The dining room and kitchen at Kitt Peak need to be upgraded and enlarged. A modern serving line is needed to comply with health code standards for a cafeteria. The dining room must be enlarged to replace table space lost to improved serving lines and to continue to accommodate usage not only by NOAO staff but by personnel from McGraw Hill Observatory, Steward Observatory, Warner and Swasey Observatory and the National Radio Astronomy Observatory.

A second story addition to the KPNO #1-0.9m telescope building is needed. The addition is to house increased computer and electronics required by CCD systems and to provide a console room and astronomers office. This telescope is currently as oversubscribed as the KPNO 4m telescope.

A combined first aid, fire station, and security building is needed in a central location on Kitt Peak. Presently the first aid station is located in
a dormitory room that is needed for nighttime users, and the fire station is located down a hill in the maintenance area away from all telescope buildings. During winter with snow and ice on the road, it is difficult to drive the fire truck up the hill. A combined first aid, fire station, and security building located "on top" near the Visitor Center would be the logical place for public visitors to go to obtain emergency first aid treatment or to initiate searches for children separated from their group.

An auditorium addition is planned for the Kitt Peak Visitor Center to handle the very large increase in public visitors over the past ten years. The auditorium will permit frequent film viewing separate from general exhibits, a place for guest speakers, review of current research activities conducted on Kitt Peak, and other issues affecting astronomy.

An addition to the Kitt Peak administration building is needed to provide adequate space for the scientific library, laboratory facilities for computers, and to alleviate the acute shortage of office space.

Larger, more spacious dormitory facilities are needed for the permanent employees assigned to work on Kitt Peak. Permanent employees are currently assigned a dormitory room only large enough to accommodate a single twin-size bed, and thus the rooms are too small for long term accommodations. A minimum of five dormitory rooms built as studio apartments are needed for resident staff members.
C. NOAO-Tucson

The NOAO reorganization requires a thorough study of space utilization and needs at the NOAO Tucson complex. During the early part of this plan we will be conducting such a study, and presenting a master site plan to the NSF. (Master plans will also be submitted for the other NOAO sites.) It is anticipated that this study will result in a need for some interior remodeling of the main NOAO building, to better accommodate the needs of an organizational structure that differs from that which was in existence when the building was constructed. Two specific needs are a plate-storage facility and the Tucson library extension.

Recent studies have revealed significant deterioration of some of the photographic plates in the KPNO plate collection. This collection is a valuable national resource consisting of 6000 Palomar Sky Survey plates, about 4000 original KPNO plates, and the 660 plates of the recently acquired Southern Sky Atlas. To prevent further damage an environmentally controlled plate storage facility is needed at the Tucson headquarters.

The Tucson library is one of the best astronomy libraries in the world, but it has very nearly run out of shelf space. A simple expansion to the library can be made which utilizes existing structural members and thus greatly reduces the cost. Such an expansion would provide the necessary shelf space for a period of about ten years.
IX. MAJOR MAINTENANCE AND FACILITY EQUIPMENT

The category of major maintenance and facility equipment incorporates a range of actions long desired and too frequently the first to be postponed in budgetary crises of the kind that have characterized the national optical observatories in recent years. Deferral of maintenance has its cost—not only in reduced reliability, but in subsequent costs of repairs. We hope to be able to allocate sufficient funds from the core budget (as set out here) to accommodate most items in this category. However, some added funds (included under Program Development) will be needed to carry out the full program set out and advocated here.

The items set out below represent established needs. Again, however, consideration by the new NOAO management will no doubt show other critical needs and will allow a prioritization across the NOAO. A tabulation of needs with brief justification follows.

- Over the last few years many minor modifications to the grating-ruling engine and facility have been completed. With these improvements the engine has been able to produce high quality rulings of moderate spacing (<800 lines per millimeter), blaze angle (<45°), and size (<250 millimeters). However, it has failed to produce high quality, very large (300-400 millimeters) gratings with high blaze angle (>60°) or fine pitch (800-1200 lines per millimeter) such as are now being requested. During the early years of this plan the NOAO will implement major modifications to the ruling engine and facility. The
changes will effectively produce a new modernized ruling engine through the following actions:

(a) Replacement of nearly quarter century old control-system electronics with a new generation interferometric control system for improved performance, reliability, and maintainability.

(b) Replacement of the mechanical diamond carriage drive (bell crank with mechanical cam motion corrections) with a digitally-servoed linear motor-drive assembly. The diamond carriage will be redesigned to incorporate a pneumatic bearing to eliminate friction.

(c) Implementation of full standby power system for electrical and HVAC. This is needed because as the duration of the rulings increases (due to larger size and finer pitch) the probability of failures in rulings due to commercial power outages increases significantly.

- Additional electrical power capacity and backup equipment is needed for Cerro Tololo. Commercial power is considerably less expensive than running diesel generators.

- A supplementary emergency power generator is needed for the La Serena compound offices, residences, shops, and computer center. The present generator is barely capable of supplying power needs for the computer center's air conditioning units and the compound water system.
• Painting and refurbishing telescope and other buildings on Kitt Peak and replacing old buildings, are urgently needed.

• In Tucson, a variety of badly needed actions including re-roofing, replacement of heating and air conditioning equipment, paving and fencing of parking facilities, and upgrading telephone systems.

• Provision of an upgraded fire protection system in Tucson has been twice deferred and grows more urgent.

• A 12-inch aperture optical test interferometer is proposed for the NOAO Optical Shop. This device will be used for the testing of diffraction gratings and small optics. Systems of this type are available from a number of manufacturers and have, during the last decade, become a standard piece of equipment in shops which manufacture custom optics. For testing larger optics, it is planned that the digital TV Hartmann and interferometric optical test data acquisition system which was prototyped during FY 1983 be fully implemented.

• Coating facilities improvements. The results of high reflectivity broad-band coating studies carried out under the NNTT Technology Development Program will be implemented in the Tucson, Kitt Peak, and Cerro Tololo optical coating facilities early in the plan period. These will likely take the form of new types of deposition hardware as well as additional deposition monitoring equipment.
A detector test facility to be constructed in La Serena utilizing an existing detector controller/computer system along with additional optical hardware. This will be a duplicate of a system which will be in service in Tucson by mid-FY 1986. The purpose of this system is to allow precise laboratory evaluation of the spatial photometric properties of optical and infrared detectors. The system will provide close simulation of the actual optical systems in which new detectors are to be used. The system will be used to directly measure the relative sensitivities of different detectors as well as monitor the long-term variation in the photometric properties of in-service detectors. One major benefit of the system is that it will permit the performance of tests in the laboratory which currently require the use of telescope time.
X. CONCLUSION

This long range plan has been prepared during a transitional period for the national optical observatories. As such, it lacks the cohesiveness that we shall aim for in subsequent plans.

With the formation of the Central Computer Services unit in October 1984, the reorganization of the national observatories into the NOAO, will be essentially complete. A priority item for the new NOAO management during FY 1985 is the formulation of a long range plan which will accurately reflect the goals of the NOAO for the period of the plan, and the means by which we will meet these goals. Additionally, we intend that this new approach to long range planning will allow a more integrated relationship between the annual program plan and the long range plan.
Table 1
NATIONAL OPTICAL ASTRONOMY OBSERVATORIES
FY1986 - FY1990 LONG RANGE PLAN
BUDGET SUMMARY

(Amounts in Thousands)

**CORE BUDGET**

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**PROGRAM DEVELOPMENT BUDGET**

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**TOTAL BUDGET**

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1 Includes $1,200K anticipated carryover from FY-1984 and $415K anticipated funding from USAF.

2 Includes operating costs.
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TOTAL NOAO: $14,714, $14,580, $14,443, $14,306, $14,169, $14,032

## Table 3

**NATIONAL OPTICAL ASTRONOMY OBSERVATORIES**  
**FY1986 - FY1990 LONG RANGE PLAN**  
(In Full Time Equivalents)

### CORE BUDGET

By Long Range Plan Category

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**By Function**

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**TOTAL CORE BUDGET AND PROGRAM DEVELOPMENT BUDGET**

|                                | 509.80  | 534.40  | 549.00  | 586.40  | 593.40  | 590.40  |